Measurement of neutral current cross sections at high Bjorken x with the ZEUS detector at HERA

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Abstract.
The neutral current cross section is measured at high-Q^2 and up to Bjorken-x values of one with the ZEUS detector at HERA using an integrated luminosity of 142 pb^{-1} of positron proton collisions at center of mass energy 318 GeV. The analysis relies on the presence of jets expected in high-Q^2 events and a new method is proposed to reconstruct the kinematic variable x with improved resolution. The measurement is expected to constitute an important constraint on existing parton density functions (PDFs).

Keywords: Deep Inelastic e^+p Scattering, Neutral Current, Proton Structure Functions, high Bjorken x, HERA, ZEUS
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INTRODUCTION AND MOTIVATION

Deep inelastic scattering (DIS)[1], is by far the most accurate process for extracting parton distribution functions (PDFs)[2] and hence enhancing the knowledge about proton structure. These PDFs cannot be calculated from first principles and need to be extracted from measurements. A precise knowledge of PDFs in the full kinematic range is particularly important now when the Large Hadron Collider (LHC) had started to deliver the proton-proton collisions. The DIS is expressed usually in terms of three Lorentz-invariant quantities, Q^2, x and y, which are related by $Q^2 = sxy$, where the mass of the electron and the proton are neglected, s is the square of the center-of-mass energy, Q^2 is negative of the square of the transferred momentum, x is the Bjorken variable and y is the in-elasticity.
Due to limitations of measurement techniques and small cross sections only limited information is available at high x. For $x \geq 0.3$, the PDFs are found to decrease very quickly. However, a direct confrontation of calculations with data has not been possible to date for $x \to 1$. The highest measured points in the DIS regime are for $x = 0.75$[3]. Data at higher x exist [4] but these are in the resonance production region and cannot be easily interpreted in terms of parton distributions. The highest x value for HERA structure function data reported to date is $x = 0.65$ [5]. The differences between different PDF sets increase rapidly as x increases, even though they use same data and have similar

[1] Speaker

functional forms for $x \to 1$. The uncertainties for $x > 0.75$ are large and hard to quantify. A first attempt to explore the region of $x \approx 1$ and $Q^2 > 650$ GeV^2 was performed by the ZEUS collaboration on the 96-00 data [6].
This new measurement is based on the positron-proton collision data collected with the ZEUS detector after the luminosity upgrade of the HERA accelerator (HERA II) at the center of mass energy, $\sqrt{s}$=318 GeV. New technique was developed to improve reconstruction of the kinematic variable x.

METHODOLOGY

A typical high-x and high-Q^2 event in NC DIS consists of the scattered electron and a high energy collimated jet of particles following the direction of the scattered quark (Fig.1). The proton remnant mostly disappears down the beam pipe.

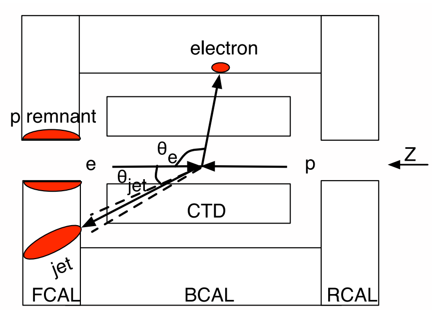

FIGURE 1. A schematic depiction of the ZEUS detector with the main components used in this analysis. Also shown is a typical topology for a one jet NC event. The electron is scattered at a large angle and is reconstructed using the central tracking detector (CTD) and the barrel calorimeter (BCAL), while the scattered jet is typically reconstructed in the forward calorimeter (FCAL). The proton remnant mostly disappears down the beam pipe [6]

The kinematic range accessible to the measurement is determined by the resolution on x and Q^2. In high-x events the electron detection efficiency is close to 100%. Electrons provide a good resolution on the momentum transfer Q^2 which can be expressed as follows:

$$Q_e^2 = 2E_e E_e^{'}(1+\cos\theta), \qquad (1)$$

where E_e is the initial energy of the electron and $E_e^{'}$ and θ are the energy and the polar angle of the scattered electron. The electron method gives poor resolution on x. In order to improve the x measurement in the ZEUS detector, information on the hadronic final state can be included, which was referred to as jet method. The jet information can be used to calculate x as follows;

$$x = \frac{E_{\text{jet}}(1+\cos\theta_{\text{jet}})}{2E_p\left(1-\frac{E_{\text{jet}}(1-\cos\theta_{\text{jet}})}{2E_e}\right)}, \qquad (2)$$

where E_p is the proton beam energy and jet variables are according to Snowmass convention [7]. The events in which the jet was very close to beam pipe were not well reconstructed (zero jet events), and were termed as high-x events. Only integrated cross section was calculated for such events. Since the momentum and energy of the electron can be determined more precisely than the jet energy, in this analysis a new approach (based upon momentum balance between electron and jet) was implemented in which the jet energy term in eq. (2) was substituted by

$$E_{jet} = p_{T\mathrm{jet}}/\sin\theta_{\mathrm{jet}} = p_{T\mathrm{e}}/\sin\theta_{\mathrm{jet}}, \tag{3}$$

Using this method for one jet events resulted in improved x resolution (for the x reconstruction of multi jet events expanded notation of the jet method was used).

RESULTS

Comparison between the MC expectation and the 2006-07 e^+p data (L = 142pb^{-1}) for several electron, jet and kinematic variables is shown in Fig. 2 and Fig. 3, respectively. After detector calibration, good agreement between data and MC simulation is observed.

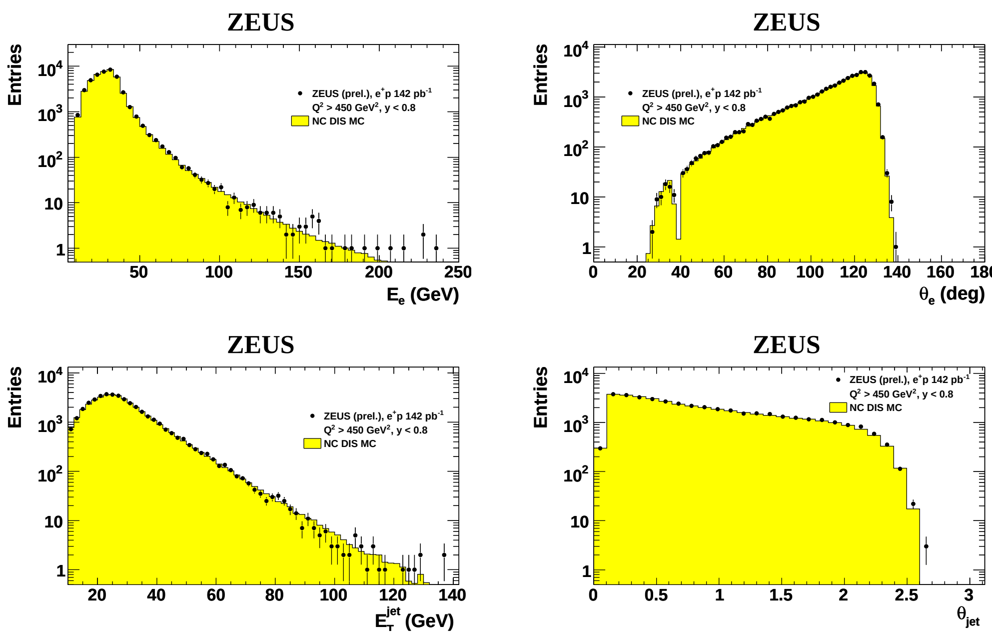

FIGURE 2. Comparison of NC MC distributions (histograms) with 2006-2007 e^+p data (points) for: the energy of the electron E_e (top-left) and the polar angle of the electron θ_e (top-right), the sum of transverse energy of the jets E_T^{jet} (bottom-left) and the weighted polar angle θ_{jet} (bottom-right) of the jets. The MC distributions are normalized to the measured luminosity.

NC DIS cross sections was measured at large values of x including the region $x \approx 1$, in particular in the region of $Q^2 > 575$ GeV^2 and $0.1 < x < 1$. Good agreement with Standard Model CTEQ6D[8] and HERAPDF1.5[9] predictions is presented in the double differential cross section Fig. 4. The agreement is good also at last integrated x bins. This measurement is expected to constitute an important constraint not only on PDFs at large x but in the whole phase space, because of the inherent couplings between the small and the large x PDFs.

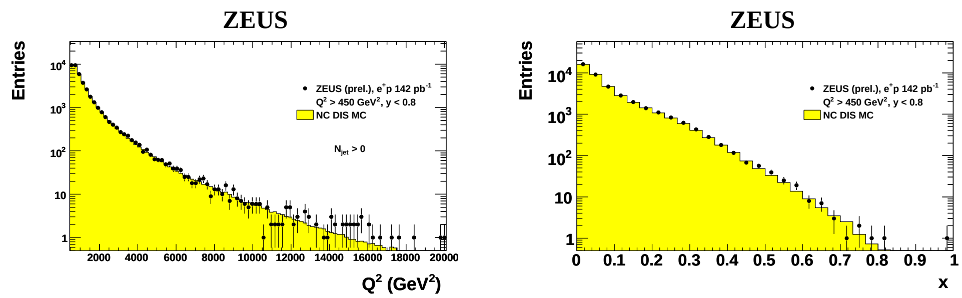

FIGURE 3. Comparison of NC MC distributions (histograms) with 2006-2007 e^+p data (points) for kinematic variables: Q^2(left), Bjorken x(right). The MC distributions are normalized to the measured luminosity.

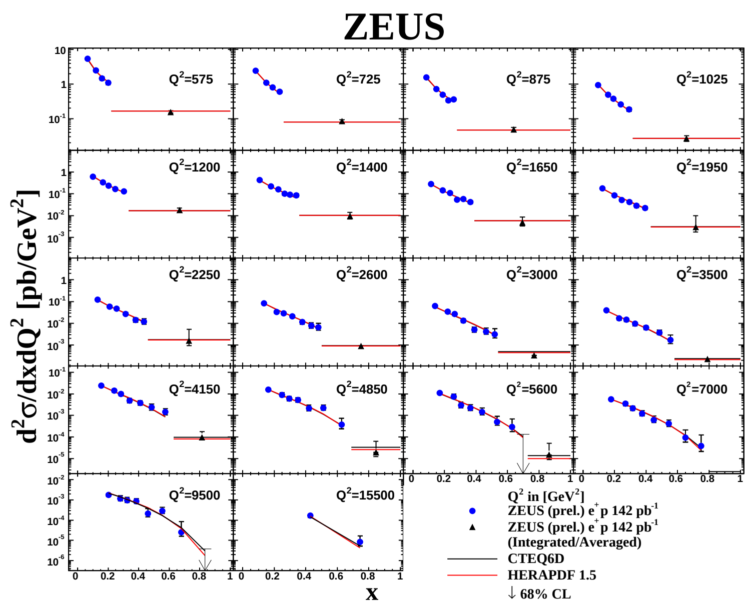

FIGURE 4. The double differential cross section for 2006-2007 e^+p NC scattering at $\sqrt{s} = 318 GeV$ (blue circles) and the integral of the double differential cross section divided by the bin width (black triangles) compared to the Standard Model expectations evaluated using CTEQ6D PDFs (black line) and HERAPDF1.5 (red line). For bins with zero measured events, a 68% probability limit is given.

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